Solar Origins of Space Weather: Confronting Models with Observations

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LONG-TERM GOALS

The major goal of this project is to acquire and use improved observational data to test predictive models of space weather events.

OBJECTIVES

There are three primary scientific objectives of this project: (1) Develop methods to acquire and use new observations to enhance understanding and forecasting of solar eruptions that produce significant space weather events. (2) Test models that intend to predict solar activity by confronting model predictions with actual observations. (3) Explore observational diagnostics that offer promise for predicting and modeling space weather events.

APPROACH

For objective 1, we concentrate on development of reduction, calibration, display, storage and community access methods to be used with data recently becoming available from the new SOLIS suite of synoptic observing equipment. We also develop methods to calibrate unique magnetic field data from the worldwide GONG instruments.

Achieving objective 2 involves construction of models that have potential to predict the occurrence of solar activity. These models are used with real data and then the predictions are compared with actual space weather events.

The approach for objective 3 is to try new types of data and new ways of looking at old data to find promising predictors for the occurrence of space weather events.

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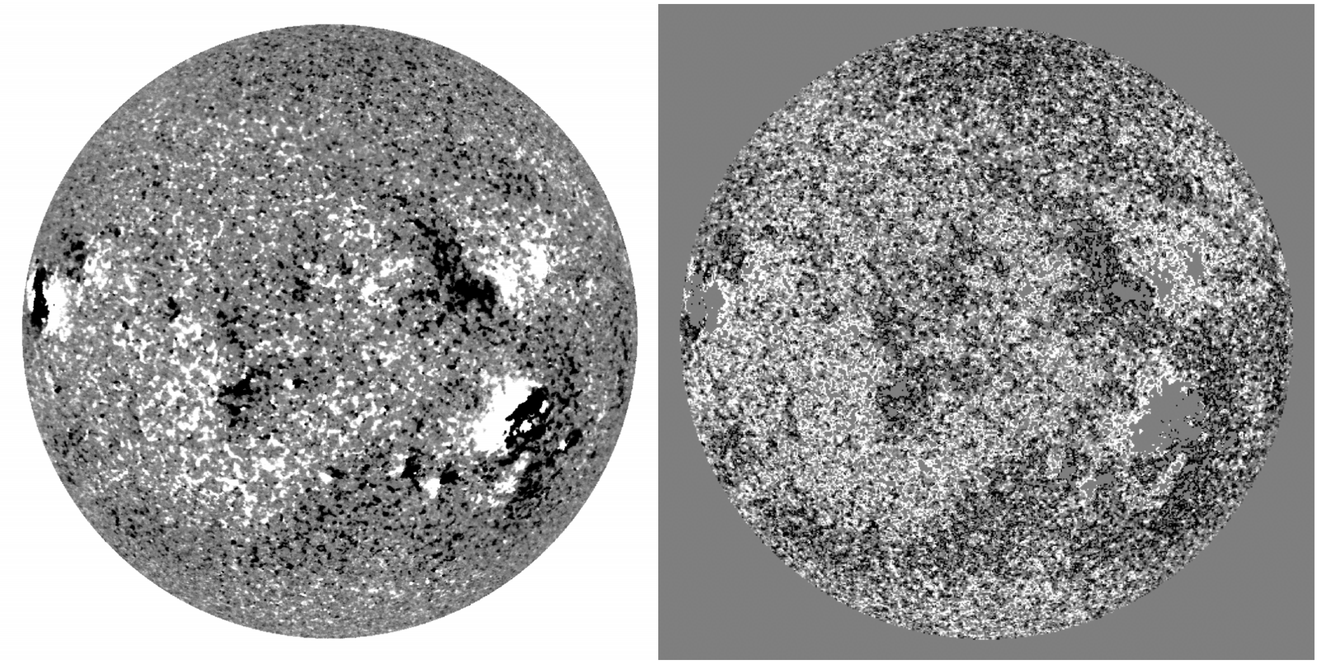
The individuals participating in this work are Dr. John Harvey, PI, who directs and organizes the work of the project and concentrates on calibration and display methods for SOLIS and GONG data, Dr. Frank Hill, Co-PI, who concentrates on the development of new SOLIS codes, data storage and access for both SOLIS and GONG data, and educational outreach. Dr. Carl Henney, Assistant Astronomer, who has developed SOLIS data reduction codes and does the formulation and verification of predictive models, and works on community data access and educational outreach, and Dr. Roberta Toussaint, Assistant Scientist, who is an expert on the calibration of GONG data and is now developing calibration codes for SOLIS instruments. We also collaborate closely with personnel in the GONG project.

WORK COMPLETED

The major accomplishment was bringing the SOLIS vector spectromagnetograph to initial service after five years of design, development and construction. This new, state-of-the-art instrument is completing a period of overlapping observations made with an old instrument that SOLIS will soon replace. The simultaneous observing enables linking a 30-year archive of past data with the new SOLIS data. Thanks to work supported by this award, the new data produced by the complicated hardware and software system is rapidly reduced to useful form. A description of a new calibration method to determine relative gain variations in an image detector array was published (Toussaint, Harvey, Toussaint, 2003). Comparison of predicted and realized solar activity was carried out with mixed results. An automatic method for locating the boundaries of coronal holes in ground-based helium 1083 nm observations was successfully developed and implemented. A method for reducing uncertainty of the zero point of GONG magnetograms to a one-Gauss uncertainty was developed in collaboration with the GONG program.

RESULTS

A new capability became available to the solar and space physics communities in August 2003 with first observations from the SOLIS vector spectromagnetograph. For the first time, full disk measurements of the complete vector magnetic field are being made. This new view of the solar magnetic field will remove ambiguities from the interpretation of previous magnetic measurements – especially the ambiguous changes of magnetic fields associated with flares and coronal mass ejections. Early results from the new instrument show a factor of 20 improvement in signal-to-noise ratio of full-solar-disk, line-of-sight-component magnetic field measurements at moderate spatial resolution using older ground- and space-based instruments. Importantly, the new measurements are free of significant instrumental polarization and other systematic effects. This allows much weaker magnetic fields to be accurately measured and also enables detection of heretofore undetectably small changes in magnetic fields associated with solar activity. Two different spectrum lines are measured simultaneously and this permits the first estimates of magnetic field filling factor to be made on a regular basis. The high sensitivity allows magnetic fields measured with a spectrum line formed in the chromosphere to be decomposed into chromospheric and photospheric components. This height resolution adds another dimension to the regular study of solar activity. Figure 1 shows an example of the excellent sensitivity of the new observations.

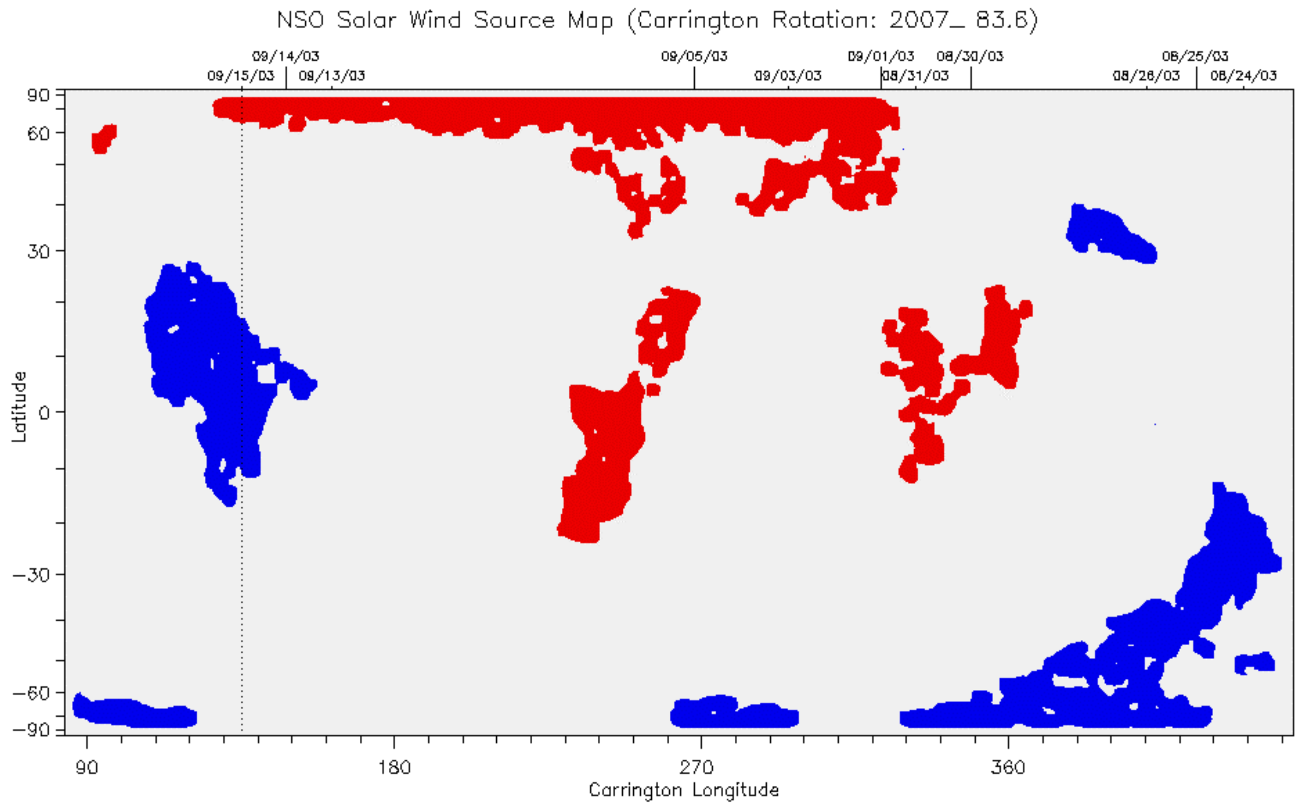


1. Line-of-sight component of the solar magnetic field observed with the new SOLIS magnetograph. The left image saturates at 15 Gauss and shows magnetic fields all the way to the solar limb with unprecedented sensitivity. The right image was processed so that all flux densities greater than 10 Gauss were set to zero and then the contrast was enhanced. This image readily shows large-scale patterns of magnetic polarities that heretofore required substantial spatial smearing or were too noisy for clear boundary definition. The boundaries between opposite polarities are the sites of most solar eruptions associated with space weather events.

In our previous annual report we described that using various single parameters derived from observations to predict the probability of future solar activity over various time periods gave generally poor results. We continued this work by developing multi-parameter predictors and independently come to the same conclusion as Leka and Barnes (2003), namely, that realizing small error rates requires multiple measures of an active region. A promising one is a combination of a measure of the spatial gradient of magnetic complexity and a measure of the length of the perimeter around a magnetic active region. A low value of this combination is successful in predicting which regions will not flare in the subsequent 72 hours. We continue to have small error rates in predicting the locations of likely solar activity. In other words, if activity occurs, it is usually within a small distance of the high alert regions of our daily forecast maps.

Coronal holes are the locations from which high-speed solar wind streams emerge – an important factor in space weather. The boundaries of coronal holes are readily determined from EUV observations that show the corona against the solar disk if overlying corona does not obscure the base of the holes. Such obscuration often occurs and then there is an advantage in using a less direct, surface indicator of coronal holes, namely, helium emission and absorption lines. We have been recording images made with the 1083 nm He I line since 1974 and drawing the boundaries of coronal holes by hand. Several past attempts to automate this process failed because the contrast of holes is subtle in the helium images. C. Henney finally solved this problem by using two techniques: multi-

scale image decomposition and improving signal-to-background ratio by averaging observations over two days. This method eliminates the subjectivity that compromised earlier quantitative studies of coronal holes and their relation to space weather. Figure 2 shows a recent example including a large coronal hole at left center (blue) that is predicted to produce a significant geomagnetic disturbance.



2. Map of the locations of coronal holes derived from 1083 nm He I observations. This map is constructed automatically every day using a new algorithm developed under this award. Blue (red) indicates outward (inward) direction of the underlying magnetic field.

J. Harvey and F. Hill worked with R. Clark and C. Toner of the GONG project to locate the source of a zero-point error in GONG magnetograms and to develop a correction method. This turned out to be difficult but now has allowed a start on the project to study the rapid magnetic field changes associated with all M and X-class flares observed since the year 2000. By virtue of good sensitivity and a one-minute observing duty cycle in excess of 80%, the GONG data are well suited for this study.

C. Henney and F. Hill continued collaboration with H. Jones in the development of the "Researching Active Solar Longitudes" (RASL, http://eo.nso.edu/rasl) educational research project. During the past year, 16 students (from two different schools) have participated in the RASL project by submitting over 2000 measurements of active region positions and areas. Henney also worked with a high school teacher, Travis Stagg from Fairbanks, AK, to develop a pretest and a post-test to measure the subject material retainment of future student participants. In addition, the RASL project was presented to Teacher Leaders in Research Based Science Education workshop participants in July 2003.

IMPACT/APPLICATIONS

Based on initial results from the SOLIS vector magnetograph, we think that it will revolutionize solar synoptic magnetic field measurements during the next 25 years. The combination of high sensitivity, ability to measure all components of the magnetic field, plus height variation and filling factor information has not been previously available on a regular basis. We expect that adding many now-possible new characteristics of an active region's magnetic field will enable greatly improved forecasting of space weather events.

TRANSITIONS

Several research and operational groups are using the data that we produce. Magnetic field and coronal hole maps are provided to the Space Environment Center in near real time to support an operational solar wind speed forecast (http://solar.sec.noaa.gov/ws/index.html). The coronal hole data is used by the Canadian government space weather forecast center (http://www.spaceweather.gc.ca). Luhmann and Li are using the maps as input to a model that attempts to detect the occurrence of coronal mass ejections before they have an influence on Earth (http://sprg.ssl.berkeley.edu/mf_evol). Linker and Mikic use our maps as boundary conditions for a sophisticated MHD model prediction of the structure of the solar corona (http://haven.saic.com/corona/model_desc.html). G. V. Rudenko at the Institute of Solar-Terrestrial Physics in Irkutsk, Russia uses our real time data and maps to construct solar corona structure estimates (http://bdm.iszf.irk.ru). Schrijver and DeRosa use our coronal hole data to validate a portion of their forecasting model (http://www.lmsal.com/forecast) and they also use our other data as a backup when spacecraft data is interrupted. In addition to the specific users listed, the data is openly available and used by many researchers and other groups around the world. A typical recent example is a paper by Xia, Marsch and Curdt (2003) in which our magnetic field and coronal hole data are used with Doppler shift measurements from space to clearly demonstrate that the solar wind is accelerated in coronal funnels, which are regions with globally open coronal fields rooted in the magnetic network.

RELATED PROJECTS

We work closely with most of the groups mentioned in the previous section. In particular, with Y.-M. Wang and N. Sheeley at NRL, C. Arge, E. Hildner and V. Pizzo at the Space Environment Center of NOAA, Y. Li at the Space Sciences Lab at Berkeley, and Yang Liu at Stanford. We participated in two workshop meetings on the subject of construction of solar synoptic data maps organized by Guiliana de Toma at the High Altitude Observatory. The SOLIS project received major construction funding from the National Science Foundation and significant additional support from NASA and this grant.

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HONORS/AWARDS/PRIZES

The Committee on Small Body Nomenclature of the International Astronomical Union honored three members of our group for their work in solar research by naming asteroids after them. Specifically: (26924) John Harvey, (31098) Frank Hill, and (31190) Toussaint.